Nuclear Fusion

# Taylor Wilson: Yup, I built a nuclear fusion reactor

<http://www.ted.com/talks/taylor_wilson_yup_i_built_a_nuclear_fusion_reactor.html>

<http://www.sciencedaily.com/releases/2012/10/121008091548.htm>

**Paving the Way for Commercial Fusion Power Plants**

*Oct. 8, 2012* — Latest results from the Joint European Torus (JET) fusion device are giving researchers increasing confidence in prospects for the next-generation ITER project, the international experiment that is expected to pave the way for commercial fusion power plants. .

Dr Francesco Romanelli said: "These results are very encouraging for ITER. JET is getting as close to ITER conditions as any present-day fusion device can. If this performance is scaled up, ITER will be successful and take a huge step towards the goal of commercial fusion power."

<http://www.guardian.co.uk/science/2012/sep/16/nuclear-fusion-iter-jet-forshaw>

**Nuclear fusion – your time has come**

Harnessing nuclear fusion to create cheap, safe and sustainable energy used to be a futuristic joke. But its day is almost upon us

* + 15 September 2012

The Joint European Torus (Jet) at Culham, Oxfordshire. Photograph: AFP/Getty Images

For a good few years now, nuclear fusion has looked like offering a solution to the problem Iit would be inherently very safe and would not produce any significant radioactive waste.

A fusion reactor called [Iter](http://www.iter.org/" \o ") is currently under construction in France and is due to start operation in 2020. Its principal goal is to determine the viability of fusion at the scale of a power station. Success is widely anticipated and there are already plans afoot to build a "demonstration power plant" to start operating in the 2030s.

Deep in the sun's core a huge mass of hydrogen falls in on itself under the action of gravity at high temperature. Under these extreme conditions two protons can fuse together, releasing energy in the process. Without this, the sun would stop burning and collapse under the weight of its own gravity.

a fusion reaction generates around a million times more energy than is released in a typical chemical reaction. Fusing protons in the sun takes a long time. For that reason Iter will not fuse protons; instead it will fuse deuterium and tritium. These are heavy partners to the proton (deuterium has an extra neutron and tritium has two extra neutrons). The extra mass helps to ensure that fusion is far easier to achieve and, combined with the fact that Iter will operate at a temperature 10 times that in the sun's core, it should be possible for Iter to generate energy at a rate of 500m watts – the level of a small power station. Unlike the sun, Iter cannot exploit gravity to compress the plasma (the name for the hot fuel mix): instead the idea is to squeeze it inside a doughnut-shaped container using magnets.

The fuel is not too hard to come by either, and it won't run out in the next few million years at least: deuterium is plentiful in seawater and tritium can be manufactured by reacting those outgoing neutrons with lithium.

It used to be joked that fusion is always the fuel of the future, but that is no longer fair. In the words of Professor Chris Llewellyn Smith, director of[energy research](http://www.guardian.co.uk/science/energy) at Oxford University, "with enough money we could probably build a fusion reactor now but it would not be economical.

. As for fusion, the bottom line is not whether we can do it but whether we can do it at a price people will be prepared to pay

[](http://news.sciencemag.org/scienceinsider/si-iter.jpg)<http://news.sciencemag.org/scienceinsider/2013/01/after-iter-many-other-obstacles-.html>

[](http://news.sciencemag.org/scienceinsider/)

# After ITER, Many Other Obstacles for Fusion Power

*by Daniel Clery*on 17 January 2013, 1:10 PM | [18 Comments](http://news.sciencemag.org/scienceinsider/2013/01/after-iter-many-other-obstacles-.html#disqus_thread)

**Like this, but bigger.** This 1:50 scale model of the future ITER reactor, produced in Korea, arrived at ITER headquarters in France on Monday where it will be put on display.

Credit: ITER Organization

The body responsible for fusion research in Europe has published a[road map](http://www.efda.org/2013/01/bringing-fusion-electricity-to-the-grid/) to get it from ITER—a giant international reactor under construction in France which will be the first to produce useful amounts of energy—to an industry-ready prototype fusion power plant by 2050. Although the successful operation of ITER, still more than 6 years away, will be considered a major breakthrough for fusion energy, the new road map from the European Fusion Development Agreement (EFDA) includes a daunting list of the technical hurdles that fusion scientists and engineers still face over the next few decades.

Fusion reactors use the power source of the sun and stars—fusing together isotopes of hydrogen—to produce energy. To do this they must compress and heat a plasma of fusion fuel to prodigious temperatures, at least 150 million°C, using powerful magnets, radio waves, and particle beams. It takes so much energy to get a plasma up to a temperature at which fusion occurs that no reactor has yet produced net energy gain.

ITER is expected to break through that barrier and generate 500 megawatts from a 50 MW input for periods lasting a few minutes. But it will be only a scientific demonstration; ITER won't generate any electricity. That job will be left for its successor, the prototype power plant DEMO. Fusion researchers are just starting to think about designs for DEMO but it is looking increasingly likely that it won't be a global collaboration like ITER, whose members are China, the European Union, India, Japan, Russia, South Korea, and the United States.

ITER and other similar modern reactors, known as tokamaks, have a structure at the bottom known as a divertor which, among other things, removes spent fuel from the plasma vessel. As the only place in the vessel where the plasma deliberately touches a solid surface, it must also absorb a lot of heat. ITER's divertor is made of stainless steel and coated with tungsten. This should work in a research reactor which operates at lower power and for at most a few minutes at a time, but DEMO will generate several gigawatts of power continuously and that heat load may be too much for a standard diverter.

EFDA also wants more work done on the so-called "tritium blanket," sections of the plasma vessel wall in which neutrons from the reactor convert lithium into tritium, one of the fusion fuels. Alternative blanket designs should be developed in case the one to be tested on ITER is not successful..

As an ultimate backup plan, the road map advocates continuing research on stellarators, an alternative fusion reactor scheme that fell out of favor when tokamaks came on the scene in the late 1960s.

<http://www.popularmechanics.com/science/energy/next-generation/is-fusion-power-finally-for-real>



# Is Fusion Power Finally For Real?

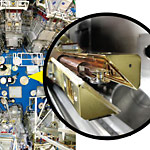
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## For decades now, a rosy future fueled by cheap, unlimited energy has always been just a few years away. Now, fusion programs including scrappy startups and billion-dollar government labs have taken the first steps toward generating star power.

**Technicians inspect the target chamber at the National Ignition Facility in Livermore, Calif.**

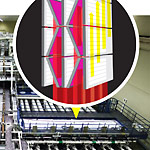
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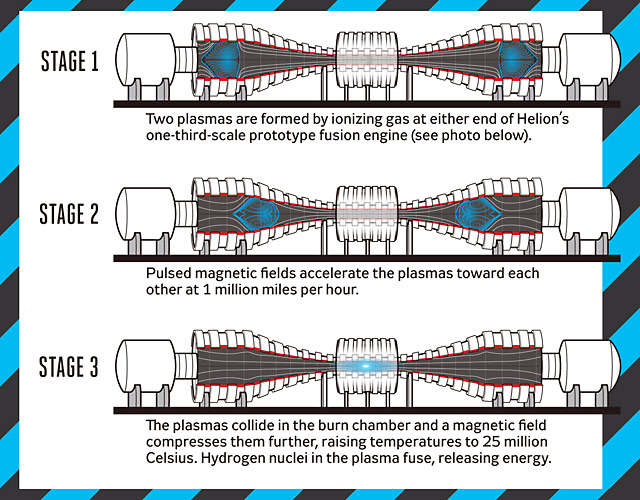
June 21, 2011

**From the other side of a wide glass window** on the third story of the National Ignition Facility (NIF), the world's largest laser array looks an awful lot like the world's largest plumbing project. Row after row of 16-inch-diameter pipes are packed into a room like cigarettes in a box—only the box is the size of three football fields. A catwalk thick with miles of cable runs through the center. Large metal ducts snake overhead and along the walls. I have to take it on faith that the pipes, called beam tubes, don't contain water or gas, but 192 separate laser beams zipping back and forth. When the beams finally exit the room, their strength amplified more than a quadrillion times, they will converge on a pencil-eraser-size target in one short, powerful pulse. And in those 20-billionths of a second, I'm told, atoms of hydrogen will smash together with such force that they'll essentially create a star.   
  
It sounds impressive—and certainly looks imposing—but society has been taking promises of fusion on faith for more than five decades. If fusion works as proponents claim, it could produce enough clean energy to power the world for hundreds and hundreds of years to come. One of the first hurdles is the tiniest component, the fuel: Hydrogen isotopes, such as deuterium and tritium, adamantly resist uniting, regardless of the amount of heat and steel and funding thrown into the effort.   
  
But this past fall, physicists at NIF, based at Lawrence Livermore National Laboratory in California, made an important advance with their elaborate building and enormous laser: They fired 121 kilojoules of ultraviolet light into the $3.5 billion facility's target chamber, causing deuterium and tritium nuclei to fuse into helium atoms, releasing 300 trillion high-energy neutrons. Even though NIF and other labs have created fusion before, the achievement brings researchers a step closer to conquering the ultimate challenge: a fusion reaction that produces more energy than is required to start it.   
  
Still, fusion has some important safety advantages over nuclear fission: To produce energy from fission, atoms such as uranium-235 are split into radioactive elements, some of which have extremely long half-lives. Nuclear fusion produces helium and neutrons, and no super-long-lived radioactive waste. Plus, fusion cannot cause runaway reactions because it requires a steady input of energy for the isotopes to fuse; any plant malfunction would cause near-immediate shutdown. Over the long term, fusion power might reduce pressure on fossil fuels such as oil and coal, while complementing clean but intermittent energy sources such as wind and solar.   
  
To produce electricity, the heat generated during a fusion reaction could be harnessed to drive a steam turbine, just as in any power plant. The difference is that fusion doesn't rely on the trainloads of coal, shipments of uranium, oil and gas drilling rigs or elaborate pipelines that feed today's facilities. Deuterium is found in seawater. "See those two water jugs right there?" says Edward Moses, the director of NIF, pointing to a display in the facility's atrium. "Those would have the energy equivalent of a supertanker of oil."

### ****Fusion from the World's Biggest Laser****

At the National Ignition Facility (NIF), "inertial confinement fusion" begins with a very small, weak laser pulse. This pulse is split into 48 beams and sent to preamplifiers, which increase the energy to a few joules. The laser is split further into 192 beams and injected into beamlines that enter two massive bays. The beams then pass through two systems of glass amplifiers, which increase their power to 20,000 joules. After leaving the main laser building, the parallel beams are rearranged into a spherical configuration by mirrors in 10-story-tall "switchyards." A final optics assembly converts the lasers' wavelength from infrared to ultraviolet, and a lens focuses them on a precise target in the center of a chamber.

**Target Chamber**   
  
NIF's target chamber contains the fuel for fusion: a dime-size gold cylinder, called a hohlraum, encasing a beryllium-coated capsule with deuterium and tritium atoms. When lasers strike the hohlraum, their energy is converted to X-rays that burn away the capsule, compressing the fuel and forcing it to implode.   
  
**Amplifiers**   
  
A system of amplifiers (shown in the laser bay) provides 99.99 percent of NIF's power. Vertical arrays of flash lamps excite neodymium atoms embedded in slabs of phosphate glass. As lasers pulse through the glass, they pick up that energy.   
**At the modest headquarters of Helion Energy in Redmond, Wash.**, the off-Broadway equivalent of the colossal NIF production is beginning to play out. The company is tucked away at the back of a nondescript suburban office park in a space not much bigger than a dentist's office; if you weren't specifically looking for Helion, you'd never come across it. A reception desk near the entrance has been repurposed into a workbench strewn with electronic components. Colored cables dangle overhead in free-form clusters, and workstations are propped up with cinder blocks. At one point, the researchers talk about a 10-tesla coil they're working on to amp up the strength of their reactor's magnetic field. "We built that coil," scientist George Votroubek says. "Have you showed her yet?" "No," his colleague Chris Pihl replies casually, "it's on the front counter."   
  
Helion is among a handful of fusion startups, such as Tri Alpha Energy in Foothill Ranch, Calif., and General Fusion in Vancouver, British Columbia, all striving for the same grand goal as their outsize government counterparts: remaking the global energy landscape by proving that fusion power is feasible. A few forward-looking venture-capital firms have provided funding to get them off the ground; Tri Alpha, for instance, has attracted more than $50 million from a variety of prominent firms, including Goldman Sachs and Vulcan Capital.   
  
Helion's technology was developed for about $5 million by MSNW, a company owned by University of Washington research associate professor John Slough. To see a full-scale component of the reactor, which Slough calls a fusion engine, I meet him at an industrial building a few minutes' drive from Helion's headquarters and walk past a conference table to a room filled with giant metal parts.   
  
Inside the 26-foot-long prototype, two plasmas—clouds of hot ionized gas containing hydrogen isotopes—hurtle toward each other. The clouds collide inside a burn chamber, merging into a single entity. An electromagnet surrounding the chamber squeezes the plasma tighter and tighter, creating the high temperature and pressure conditions needed for fusion—a milestone MSNW first passed in 2008. "The idea," says Slough, who has the white hair and slightly disheveled appearance of a modern-day Einstein, "is to have the energy that comes out of the plasma exceed the energy that goes into it for a brief period of time."   
  
Management Information ­Services senior energy adviser Robert Hirsch, a former director at the U.S. Atomic Energy Commission, argues that startup companies may have some surprising advantages. Forced by funding constraints to design systems that are as simple as possible, startups are likely to end up with clean, lean reactors instead of complex, monolithic ones, like NIF's, which have the potential to fail in dozens of different ways. "If you're going to build a successful fusion system, it's going to be inherently small," Hirsch says. With a scaled-back approach, "there is a good chance they could make something that works."   
  
The team announces that they're about to show me exactly what Helion-style fusion looks like. "You might want hearing protection for this," the company's president, ­Philip Wallace, says, handing me a pair of industrial-strength earmuffs. His colleagues power up the device. After the countdown clock on someone's iPhone drains to zero, there's a burst that sounds like a bulb breaking and a flash of pink light so bright that I have to turn away for a second. Wallace turns to me triumphantly: "You just witnessed fusion."

**The idea of generating power from fusion** has captured scientists' imaginations ever since U.S. physicist Edward Teller developed the first fusion-based hydrogen bomb, which released hundreds of times more energy than a fission bomb, in 1952. (Hot-fusion-powered approaches to creating energy are completely different from discredited "cold fusion" experiments, in which a current is passed through an electrode in heavy water in an attempt to coax nuclei to combine.) But in early tests of fusion, plasma leaked out of the confinement zone inside reactors faster than scientists had predicted, scuttling fusion reactions before they could occur.   
  
Fusion's prospects seemed to improve in the 1960s, when scientists in the Soviet Union tested a new type of fusion reactor called the tokamak. It featured a doughnut-shaped, electrically generated magnetic field that kept the plasma confined. Most international fusion research to date has followed the tokamak model; experimental tokamak reactors such as the United Kingdom's Joint European Torus (JET) and Japan's JT-60 have helped scientists understand how to confine and handle fusion plasmas. Leveraging this knowledge, 34 nations are collaborating to build the world's largest tokamak, called ITER, a demonstration project tentatively slated to start operation in France in 2019.   
  
NIF scientists have taken a completely different approach. Instead of undertaking the delicate task of confining plasma inside a magnetic field, they aim to produce a controlled version of the fusion that takes place inside the sun or a hydrogen bomb, using lasers as the reaction's driver—a technique called inertial confinement fusion. NIF's Moses notes that many of the building blocks of the project's massive laser array have already been used successfully in other industrial settings: Laser diodes similar to NIF's have enabled fiberoptic data transmission in the telecommunications industry for years. "It's a good place to be when you're riding the wave of other people's work," he says.   
  
With its pulsed magnetic field design, the Helion team claims it has found the elusive sweet spot in the fusion landscape: a reliable, cheap reactor that doesn't require fine-tuned optics or complicated plasma confinement. In Helion's reactor, electric currents flowing inside the plasma reverse the direction of a magnetic field that's applied from the outside; the new, closed field that results effectively confines the plasma. "Compared to the tokamak and NIF, Helion's reactor is relatively compact and low-cost," says Richard Milroy, a physicist at the University of Washington who isn't affiliated with Helion. "Utilities don't need to invest billions for the first test reactor to see if things will work out." Plus, he says, the plasma-formation area is separate from the burn chamber in Helion's reactor, so its expensive components may last longer.   
  
Still, all of these experimental fusion approaches face a host of scientific and practical unknowns. The massive numbers of neutrons generated during fusion may damage components of a tokamak over time, and the plasma inside can also become unstable, impeding the reaction. And even though NIF has managed to achieve partial fusion by firing individual rounds into its target chamber, similar lasers would likely need to fire 10 to 15 times every second in LIFE, the demonstration power plant Lawrence Livermore is designing for the early 2020s. That kind of consistent firing would require a laser driver with a high repetition rate, which has yet to be developed and tested.   
  
While Helion's reactor is much simpler than those of ITER or NIF, it's also not yet powerful enough to be useful to a utility. Slough says his team will need to increase the size of the reactor's magnetic confinement field and boost the acceleration rate so that the plasmas will be traveling about twice as fast by the time they crash into each other. Those refinements will require at least $15 million to $20 million in development costs, money Helion does not currently have. Even if the funds materialize, there's no guarantee the reactor will work as projected when scaled up, or function consistently over long periods of time.   
  
Wallace has traveled all over the U.S. and Europe, trying to secure money for this next phase, but, so far, firms haven't seemed interested in bankrolling a company that may take a quarter-century to start making reliable power. "Nobody's said they don't believe our science, but it's a struggle," he says. "We believe we're a long way ahead, but we're also not close to the finishing line."   
  
**Fusion from Plasmas Colliding in a Living-Room-Size Engine Surrounded by Magnets**

The fusion reactor licensed by startup Helion Energy features a field-reversed configuration, in which a closed magnetic field created by electric currents inside plasma—hot ionized gas containing hydrogen atoms—keeps the plasma confined. The magnetic field also captures high-energy helium ions created during the fusion reaction, replenishing some of the energy used to start the reaction.   
  
 **Focusing on fusion's feasibility** sidesteps a question that's perhaps more crucial: whether we should be pursuing fusion energy at all. For every optimist, there's at least one expert who believes fusion will never become a commercial reality. "One aspect that gets underestimated is the great challenge of converting the energy of fusion into useful electricity," says David LeBlanc, a physicist at Canada's Carleton University. Even when fusion reactions are successful, it'll be a very tall order to get past the fabled break-even point and create a fusion reaction that produces more energy than is needed to start it—and until that is achieved, pure fusion power is just a lab experiment.   
  
Some observers think we'd be better off scrapping fusion altogether. "These technologies are a luxury we cannot afford," says Thomas Cochran, a senior scientist in the nuclear program at the Natural Resources Defense Council. "It's hard to see how you get from here to commercialization in any cost-effective manner." Alternative energy, on the other hand, can be deployed today: Wind and solar have essentially come to technological fruition, and money spent installing turbines and arrays would immediately begin to offset carbon emissions.   
  
Even fusion's more ardent supporters agree that—given the technical issues plaguing each fusion approach and the high cost of building prototypes—it is still many years from reaching the point of adoption. "In the long run, it will be a winner. We just don't know when that time frame will be," says Stephen Dean, president of the nonprofit research firm Fusion Power Associates. "If we had a crash program, like the moon or the atom bomb project, we could do it in 15 to 20 years, but that's the most optimistic thing I can think of."   
  
Other researchers say fusion might be most useful—at least in the near term—as a means of destroying waste from nuclear fission. University of Texas physicist Swadesh Mahajan and his colleagues are developing a hybrid fusion–fission reactor that shunts neutrons produced during fusion to a fission blanket that burns nuclear waste as fuel. "Producing energy by fusion is at best a very long-term project," Mahajan says, "but through this intermediary, we can become useful to the energy sector."   
  
NIF's projected LIFE power plant will be designed to burn waste, too, and Helion is considering adapting its reactor to do the same in order to provide revenue from utilities sooner. It's easier from a technical standpoint than using fusion to produce energy, because achieving break-even is not necessary—and it could potentially help solve a long-standing problem. Using Sandia National Laboratories data, Helion calculates 50 fusion engines could incinerate the entire U.S. stockpile of nuclear waste in 20 years.   
  
Regardless of the detours fusion may take, its backers remain determined to see their initial energy quest through to its completion. Both Moses and Wallace insist that fusion power is a key component of a sustainable global future.